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A COST AND UTILITY ANALYSIS OF NIM/CAMAC STANDARDS AND EQUIPMENT FOR SHUTTLE PAYLOAD DATA ACQUISITION AND CONTROL SYSTEMS

VOLUME I. SUMMARY

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FOREWORD

A Cost and Utility Analysis of NIM/CAMAC Standards and Equipment for Shuttle Payload Data Acquisition and Control Systems was performed by the Defense and Space Systems Group of TRW, Inc. under Contract NAS9-14693 for the Lyndon B. Johnson Space Center of the National Aeronautics and Space Administration. The work was managed by Dr. Richard J. Kurz (Telephone (213) 535-2936) of the Instrument Systems Department, TRW Defense and Space Systems Group. The study was administered under the technical direction of Dr. Richard D. Eandi (Telephone (713) 483-5176) of the Space Physics Branch, Johnson Space Center.

The results of the study are presented in three volumes:

VOLUME I. SUMMARY

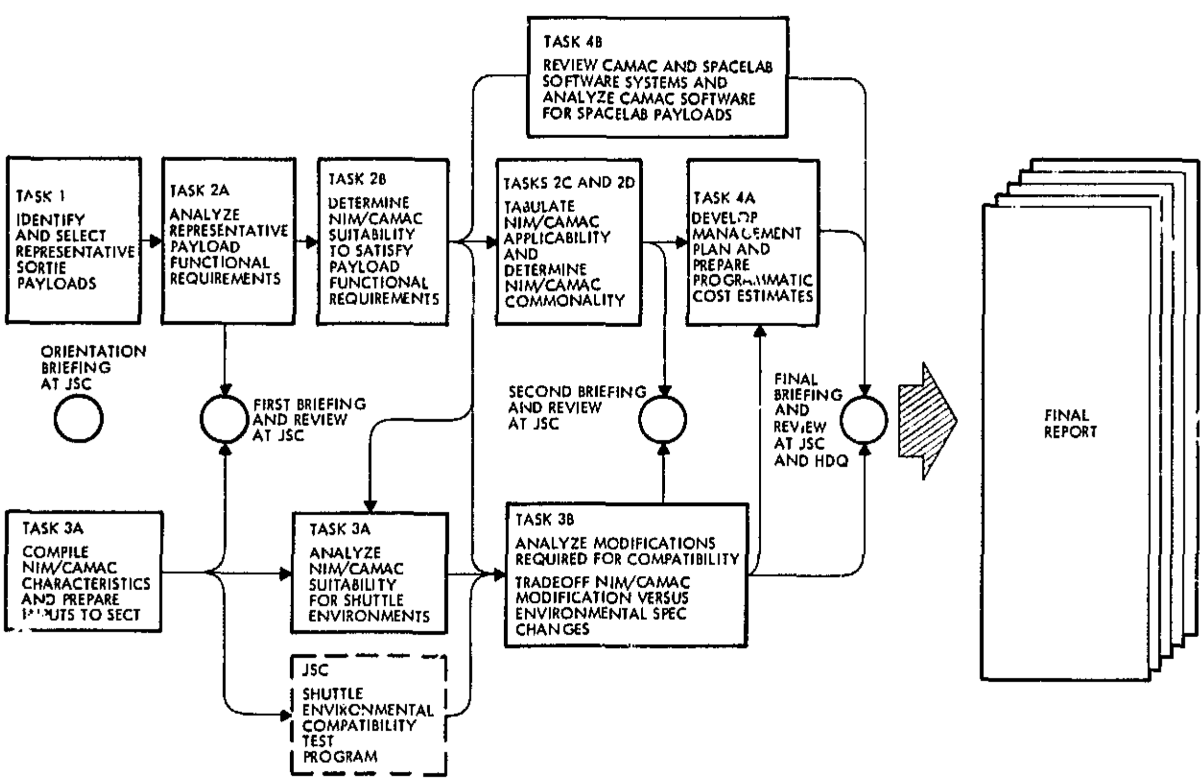
Overall summary of the analyses and conclusions

VOLUME II. TASKS 1 AND 2

Identification and selection of representative payloads for analysis and functional analysis of the selected paylaods for NIM/CAMAC equipment applicability and commonality.

VOLUME III. TASKS 3 AND 4

Analysis of the modifications to NIM/CAMAC equipment required for compatibility with the Spacelab environment and their estimated cost, development of a management plan for the utilization of NIM/CAMAC equipment and programmatic cost estimates, and assessment of the implementation and impact of CAMAC software.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STUDY SCOPE

The major objective of this study was to determine the cost-effectiveness of utilizing NIM and CAMAC equipment for Spacelab payload instrumentation. The original statement of work included four tasks:

Task 1 - Identification and selection of potential Shuttle sortie payloads for data acquisition and experiment control analysis.

Task 2 - Functional analysis of the selected Shuttle payloads to determine the applicability and commonality of NIM and CAMAC equipment in satisfying their data acquisition and control requirements.

Task 3 - Modification analysis of NIM/CAMAC equipment to determine the extent and costs of the modifications required for operation in the Spacelab environment.

Task 4A- Management plan development for implementing NIM/CAMAC standards on Shuttle including projection of the expected usage of NIM/CAMAC equipment for Spacelab payloads in the period of 1980-1991 and estimation of the programmatic costs for several implementation approaches.

Task 4 was supplemented during the course of the study to include the following task:

Task 4B- Analysis of the implementation of CAMAC software for Spacelab payloads and assessment of the impact of CAMAC on Spacelab experiment software.

Environmental compatibility testing of NIM and CAMAC equipment was conducted by JSC in parallel with this study.

TASK 1 - IDENTIFICATION AND SELECTION OF REPRESENTATIVE SHUTTLE SORTIE PAYLOADS FOR ANALYSIS

Scope of Work

- Select science and applications disciplines to be considered
- Review payload definition documentation
- Identify and select representative payloads

TASK 1 - IDENTIFICATION AND SELECTION OF REPRESENTATIVE SHUTTLE SORTIE PAYLOADS FOR ANALYSIS

Science disciplines to be considered were selected in accordance with "Scientific Uses of the Space Shuttle," National Academy of Sciences, 1974, except for the discipline of planetary exploration. Although the primary emphasis was placed on science disciplines, several applications disciplines were selected for consideration from those included in the Space Shuttle Payload Data Activity documentation.

These two references were the primary payload definition sources that were reviewed to select representative payloads on the basis of the following criteria:

- The sample should be representative of data acquisition and control requirements to be encountered in sortie-mode science and applications experiments.
- Emphasis should be placed on scientific investigations recommended in "Scientific Uses of the Space Shuttle."
- Preference should be given to those payloads that have the most complete available documentation.
- Existing NIM/CAMAC study results should not be duplicated.

One representative payload was selected from each of the seven disciplines considered. Each payload consisted of a collection of equipment or instruments that required approximately the full resources available in one sortie mission. The composite collection of instrumentation included in these payloads, when combined with the results from previous studies, represents the range of requirements that can be expected.

PAYLOADS SELECTED FOR ANALYSIS

• Atmospheric and Space Physics	AMPS
• High-Energy Astrophysics	X-Ray/Gamma-Ray Pallet
• Astronomy	One-Meter Cooled Telescope
• Solar Physics	ATM
• Life Sciences	Life Sciences Dedicated Laboratory
• Earth Observations, Earth and Ocean Physics	Earth Observations Facility
• Space Processing	Space Processing Applications Facility

PAYLOADS SELECTED FOR ANALYSIS

Atmospheric and Space Physics - A version of the AMPS (Atmospheric, Magnetospheric, and Plasmas in Space) payload, including the instrumentation required to perform six types of experiments, was selected. Results on three payloads in this discipline from a previous study by Bendix (NAS9-13784) were also used in this study.

High-Energy Astrophysics - A payload was selected that consisted of two X-ray instruments and one gamma-ray instrument. Results on a second payload consisting of two cosmic-ray instruments and one gamma-ray instrument previously analyzed by Bendix and NASA/GSFC were also used in this study.

Astronomy - A 1.0-meter, cooled, infrared telescope payload with five typical focal plane instruments was selected. Results on an optical and ultraviolet telescope facility previously analyzed by Bendix were also used in this study.

Solar Physics - A Spacelab version of the Skylab Apollo Telescope Mount experiments was selected. The payload includes six instruments for solar measurements in the X-ray, ultraviolet and visible portions of the spectrum.

Life Sciences - A dedicated Life Sciences laboratory was selected which included equipment for biochemical, biophysical, and biomedical studies.

Earth Observations and Earth and Ocean Physics - An earth observations facility including six remote sensing instruments was selected. Results from the previous Bendix study were used for two of the instruments.

Space Processing - The Space Processing Applications payload was selected. A full complement of furnace, levitation, biological, general purpose, and core equipment was included.

TASK 2 - FUNCTIONAL ANALYSIS OF SELECTED SHUTTLE PAYLOADS

Scope of Work

- Analyze experiment functional requirements
- Analyze NIM/CAMAC functional suitability
- Tabulate NIM/CAMAC applicability
- Analyze NIM/CAMAC commonality

TASK 2 - FUNCTIONAL ANALYSIS OF SELECTED SHUTTLE PAYLOADS

The available documentation for the seven representative payloads was reviewed to establish their instrumentation and functional requirements. These requirements were analyzed and a data acquisition and control system design, suited to NIM/CAMAC implementation, was developed for each of the instruments making up the payload.

Next, the specifications of currently available NIM and CAMAC equipment were reviewed and units that could satisfy the experiment functional requirements were identified. Detailed tabulations of the applicable types of NIM and CAMAC equipment were prepared at the instrument and payload level.

Results of our analyses of the seven representative payloads were then combined with the results obtained in previous studies on four additional payloads to prepare an overall tabulation of the types of NIM and CAMAC equipment found to be applicable.

Finally, an indication of the commonality of the requirements for NIM and CAMAC equipment was obtained by determining the reduction in the total amount of NIM/CAMAC equipment required to implement the eleven payloads when the equipment could be shared between paylaods.

CAMAC APPLICABILITY

- CAMAC applicability is relatively uniform over the eleven representative payloads
- CAMAC applicability is relatively uniform over the module functional types
- No requirements for functionally-modified modules were identified

CAMAC APPLICABILITY

The summary tabulation of CAMAC equipment requirements for the eleven representative Spacelab payloads is shown below.

		Astronomy			High Energy Astrophysics		Space Physics						
CAMAC Equipment	CAMAC Product Code	IR Telescope	UV Telescope (Bendix)	ATM - Solar	X-Ray/Gamma Ray	Cosmic Ray/Gamma Ray	AMPS	Atmospheric (Bendix)	Auroral (Bendix)	Life Sciences	Earth Observations	Space Processing	Totals
Scalers	111			4	23	14	6		1		1	2	51
Preset Scalers	113		5						3				8
Position Encoders	117		8		8			8	3	2	2		31
Input Gates	121	7	2	6		3	10		1	4	6	3	42
Input Registers	122							7					7
Interrupt Registers	123		3		4	3		4	2		2		18
Clocks & Pulse Generators	131	1	3	4		3		2	4				17
Output Registers	132		5			5		18	5		2		35
Output Drivers	133	6		18	5		10			1	25	4	69
Stepping Motor Controllers	145	11		18	15		15	9		6	6	6	86
Analog-to-Digital Converters	161												
High Resolution/Fast		21		7	16	3	13			20	3	4	87
Multichannel/Slow		11		6	7	8	6	1	2	12	5	9	67
Time Digitizers					26	2							28
Digital-to-Analog Converters	162	1	2	2	1	3	9		6	3	1	2	30
Multiplexers	164	3		3		1			2	9	2		20
Branch Drivers	211	1	1	1	1	1	1	2	2	1	1	1	13
Crate Controllers	231	4	2	4	6	3	4	4	3	4	3	2	39
Crates w/Power Supply	411	4	2	4	6	3	4	4	3	4	3	2	39
Totals		70	33	77	118	52	78	59	37	66	62	35	687

The numbers of modules needed in each payload are tabulated by functional type. The largest numbers of any particular type of module required in one payload are circled. One sees immediately that the applicability of CAMAC equipment is relatively uniform over the eleven payloads. The average payload usage is 62 units with a maximum variation of a factor of two. As expected, high-energy astrophysics is the heaviest user of CAMAC equipment.

In addition, the distribution of applicability among the various function types of CAMAC modules is also relatively uniform. Analog-to-digital converters, stepping motor controllers, and output registers are the most frequently used types of modules.

Essentially no payload data acquisition and control requirements were found that could not be satisfied with existing CAMAC equipment.

NIM APPLICABILITY

- NIM applicability is concentrated in the high-energy astrophysics payloads
- Only NIM amplifiers and high-voltage power supplies have reasonably broad applicability
- Limited applicability plus inefficient packaging make implementation based directly on commercial NIM equipment questionable

NIM APPLICABILITY

The summary tabulaticn of NIM equipment requirements for the eleven representative payloads is shown below.

NIM Equipment	Astronomy: IR Telescope	Astronomy: UV Telescope (Bendix)	Astronomy: ATM - Solar	High-Energy Astrophysics: X-Ray/ Gamma Ray	High-Energy Astrophysics: Cosmic Ray/ Gamma Ray	Space Physics: AMPS	Space Physics: Atmospheric (Bendix)	Space Physics: Auroral (Bendix)	Life Sciences	Earth Observations	Space Processing	Totals
Pulse Amplifiers												
Shaping			10	42	8	4		11		1	3	79
Fast					2							2
Delay					3							3
Sum/Invert				49		1						50
Discriminators												
Fast Integral				22	9							31
Slow Integral			10		6	5						21
Window										1	3	4
Zero-Crossing				7								7
Constant-Fraction					12							12
Linear Gates			1									1
Linear Fan-Ins					12							12
Linear Fan-Outs					3							3
Logic Units				19	3							22
Pulse Height Analyzers						1						
High Voltage Power Supplies	5	2	9	42	8	40		7			3	116
Bins w/Power Supply	1	1	2	17	7	8		4		1	1	42
Totals	6	3	32	198	73	59	–	22	–	3	[illegible]	406
Special Modules												
Sequence Discriminators				7								
Wave Analyzers						8						
Differential Amplifier						6						

In contrast to the situation for CAMAC, NIM applicability is heavily concentrated in the high-energy astrophysics payloads. About seventy percent of the total usage occurs in this single discipline. While the dis- tribution of usage among the various functional types of modules is fairl uniform in this discipline, only NIM amplifiers and high-voltage power supplies find any degree of general applicabilty.

Some requirements were identified for functions not currently available in NIM for which NIM packaging could be used. On the other hand, many requirements were also identified for which NIM packaging was not suitable. In addition, for the most applicable type of NIM equipment, high-voltage power supplies, the use of NIM packaging is not attractive for Spacelab applications for many reasons.

In summary, we concluded that the limited applicability and unattractive packaging features of NIM equipment make the development of standard modules specifically designed for spaceflight application a more reasonable approach.

COMMONALITY ANALYSIS

- Simplified analysis involves comparing the number of units required for serial flights as opposed to parallel flights
- CAMAC commonality is high in all categories of equipment
- NIM commonality only approaches that found for CAMAC in the case of high-voltage power supplies confirming the conclusion reached on the basis of its limited applicability

COMMONALITY ANALYSIS

A simplified analysis of the commonality of requirements for NIM/CAMAC equipment was performed by comparing the amount of equipment that would be required if the eleven payloads were flown in parallel as opposed to the amount required if they were flown in a serial sequence.

For the serial flight sequence, only the numbers of each type of NIM/CAMAC equipment that were circled in the summary tabulations would be required. For the parallel flight case, the total numbers in the right-hand column of the summary tabulations would be needed.

For CAMAC equipment, the serial case required a total of 217 units. as opposed to 687 units in the parallel case. Fo, NIM equipment, the corresponding numbers are 245 versus 405. Thus, if users can share the same equipment, the increased commonality of requirements for CAMAC equipment results in a reduction of almost seventy percent in the number of units needed compared with a reduction of forty percent for NIM equipment. This result only confirms the conclusions reached on the basis of the applicability tabulations.

TASK 3 - MODIFICATION ANALYSIS OF NIM/CAMAC EQUIPMENT

Scope of Work

- Assemble and evaluate NIM/CAMAC and Spacelab information
- Analyze NIM/CAMAC suitability for Spacelab environments
- Analyze required modifications and determine costs

TASK 3 - MODIFICATION ANALYSIS OF NIM/CAMAC EQUIPMENT

The available data on NIM/CAMAC equipment and Spacelab environments was compiled and reviewed to make a preliminary assessment of the problems that might be encountered in using NIM/CAMAC equipment for Spacelab payloads. Since very little published information is available on the environmental characteristics of NIM/CAMAC equipment, the conclusions were based on inspection of typical units and discussions with users. Preliminary recommendations for the environmental testing to be performed by JSC were formulated on the basis of our preliminary assessment of the compatibility of NIM/CAMAC equipment with the Spacelab environments.

Detailed structural and thermal analyses were performed to make a more quantitative assessment of the suitability of NIM/CAMAC equipment for Spacelab applications and to determine the specific modifications that would be required to assure compatibility. Further recommendations for the JSC environmental test program were also generated.

The minimum modifications to commercial NIM/CAMAC equipment that would be required for its use in Spacelab were identified and an estimate of the cost of these modifications was made. In addition, recommendations were made for more extensive modifications that would assure reliable operation and the cost of these modifications was also estimated.

DYNAMIC ANALYSIS

- Detailed analysis concentrated on CAMAC equipment because of its higher applicability
- Random vibration was the driving dynamic environment for rack-mounted equipment
- Analytical results indicated that the basic structure is more than adequate and only relatively minor modifications are required

DYNAMIC ANALYSIS

The detailed dynamic analysis was performed on a finite element computer model of the CAMAC structure. The analysis concentrated on CAMAC equipment because of its higher applicability. Since the structural characteristics of NIM equipment are very similar, the results are also applicable in that case.

Our analysis of the Spacelab dynamic environments for rack-mounted equipment indicated that random vibration would place the most severe requirements on the equipment. The analysis was performed with an overall random vibration level of twelve grms although the most recent estimates of the Spacelab environment are considerably lower. The results should therefore be conservative.

The principal results of the dynamic analysis were the following:

- The resonant frequencies of the important modes are low enough (50 - 100 Hz) to require careful attention to stress relief of wiring.
- The basic structural elements have a margin of safety of 1.9, and are hence very adequate.
- Circuit board stresses and deflections are well below acceptable normal levels for spaceflight electronics so normal component mounting will suffice.
- Peak accelerations should not result in problems with the types of components and parts normally used in NIM/CAMAC equipment.

The general conclusion was that only minor modifications would be required for compatibility with the Spacelab dynamic environments.

THERMAL ANALYSIS

- Thermal analysis was based on the forced-air convective cooling provided by the Spacelab avionics air loop with appropriate crate or bin ducting to assure uniform air flow
- Circuit board temperatures were calculated as a function of air flow velocity and power dissipation
- Analytical results indicate that nominal Spacelab airflow is marginally adequate and module power reduction is desirable

THERMAL ANALYSIS

Our preliminary assessment indicated that NIM/CAMAC equipment could only operate with forced-air convective cooling unless significant changes were made to improve the conductive heat transfer and reduce the power dissipation. Therefore, the thermal analysis was based upon the forced-air conductive cooling provided by the Spacelab avionics air loop. Appropriate modifications to the crate or bin ducting were assumed.

Circuit board temperatures were calculated as a function of air flow velocity and circuit power dissipation. The results are presented in the form of graphs that can be used to estimate the operating thermal environment at the part level.

The analytical results indicated the following:

- The nominal Spacelab air flow is marginally adequate for equipment using industrial-grade parts (maximum operating temperature of 70 °C).

- The margin is sufficiently small to require careful attention to any deviation from the nominal conditions such as points of above average local power dissipation.

The general conclusion was that module power reduction is highly desirable to increase the margin or reduce the air flow requirements. The use of electronic parts capable of operating at temperatures up to 125 °C is also recommended.

MODIFICATION COSTS

- Minimum modifications required correspond to those identified in the Rockwell study (NAS8-30451)

    - Nonrecurring DDT&E = $11 K/module
    - Recurring unit cost = $1250/module

- Costs were estimated for more extensive modification

    - Nonrecurring DDT&E = $49 K/module
    - Recurring unit cost = $4830/module

- For comparison, costs were estimated for comparable equipment built to current space electronics standards

    - Nonrecurring DDT&E = $125K/module
    - Recurring unit cost = $6250/module

MODIFICATION COSTS

In order to be in a position to assess the sensitivity of programmatic costs to the degree of modification performed on NIM/CAMAC equipment, cost estimates were prepared for three levels of modification ranging from the minimum necessary to complete conformance with current standards for spaceflight electronics. As a point of reference, the average cost of a commercial NIM/CAMAC module is about $700.

The minimum modifications to NIM/CAMAC equipment required for use in the Spacelab module amounted to some relatively minor structural changes to the crates and modules, the addition of an air-flow ducting arrangement that is compatible with the Spacelab avionics cooling air loop and the adoption of some standard aerospace practices for circuit board assembly. Since these modifications correspond closely to the type identified in a previous analysis by Rockwell of the use of commercial equipment for Spacelab payloads (NAS8-30451), the estimated modification costs were based on the cost estimates contained in the Rockwell study.

The more extensive modifications that were considered involved a design analysis of the existing circuitry to both increase its reliability and reduce the power consumption. The resultant changes would be incorporated in a new circuit board layout and the modules would be manufactured in accordance with current minimum standards for spaceflight electronics. The estimated costs to perform these more extensive modifications were derived from the results of a previous TRW study (NASw-2717) of standard modular electronics for experiments flown on automated spacecraft.

The cost estimates for functionally equivalent equipment, developed in full accordance with current standards for spaceflight electronics, were taken directly from the previous TRW study.

TASK 4A - MANAGEMENT PLAN DEVELOPMENT

Scope of Work

- Develop time-phased NIM/CAMAC equipment requirements
- Perform a tradeoff analysis of NIM/CAMAC equipment pool concepts
- Prepare a management plan based on the recommended pool concept
- Prepare comparative equipment cost estimates for program implementations that do not involve a pool approach

TASK 4A - MANAGEMENT PLAN DEVELOPMENT

Experience with NIM/CAMAC equipment usage at ground-based laboratories indicates that an equipment pool approach to implement the sharing of common equipment by users is cost-effective. Our work in Task 4A was directed at making a more realistic assessment of the impact of equipment sharing than was provided by the commonality analysis of Task 2.

Time-phased NIM/CAMAC equipment usage requirements for Spacelab payload operations during the period of 1980-1991 were developed by using the representative payload results from Task 2 and a baseline Spacelab payload traffic model.

Alternative equipment pool concepts to implement a shared-equipment approach for Spacelab payloads were defined and analyzed. A recommended pool concept for NIM/CAMAC equipment in the Spacelab aea was developed on the basis of this analysis and pool operational costs were estimated.

Next, the NIM/CAMAC equipment usage requirements for Spacelab payloads were converted to pool size requirements and time-phased equipment procurement requirements. This information, along with the modification cost estimates from Task 3, formed the basis for a programmatic estimate of the pool equipment costs. A management plan was then prepared for the recommended pool concept.

Finally, comparative cost estimates were prepared for Spacelab program implementations that did not involve an equipment pool approach. In these cases, equipment was assumed to be dedicated to each payload. Both dedicated NIM/CAMAC equipment and dedicated custom-built equivalent equipment were considered.

BASELINE PAYLOAD MODEL AND NIM/CAMAC EQUIPMENT REQUIREMENTS

YEARS	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
SSPDA MODEL (PAYLOADS/YEAR)	10	16	17	20	24	25	26	22	24	22	23	20
NOVEMBER '74 MODEL (SPACELAB FLIGHTS/YEAR)	2	6	12	17	19	21	21	24	24	24	27	29
EQUIPMENT USAGE (UNITS/YEAR)												
CAMAC	156	425	645	965	990	1066	1096	1156	1218	1071	1255	1292
NIM	210	141	324	478	366	507	376	523	387	523	398	548
TOTAL	366	566	969	1443	1356	1573	1472	1679	1605	1594	1653	1840

BASELINE PAYLOAD MODEL AND NIM/CAMAC EQUIPMENT REQUIREMENTS

A baseline Spacelab payload traffic model was defined for the time period of 1980-1991 from the 1974 Shuttle 572-flight traffic model. The flight frequencies and distribution among disciplines were checked against a payload model derived from the SSPDA tabulations. To construct this model, the SSPDA data were converted to the numbers of full Spacelab payloads per year that would be required to fly the experiments listed in each discipline. The two models are generally consistent except for the early years when the available flights are oversubscribed by the SSPDA model. The baseline Spacelab payload traffic model used in this study to estimate equipment requirements projects 226 Spacelab flights for the 1980-1991 time period.

The yearly NIM/CAMAC equipment usage shown on the facing page was calculated by multiplying the representative NIM/CAMAC equipment requirements for each discipline by the number of flights in each year assigned to that discipline in the baseline Spacelab payload traffic model. For the disciplines in which the results for more than one payload were available from Task 2, the average NIM/CAMAC equipment requirements were used.

The annual usage rises through 1983 as the number of flights per year increases to reach a level that remains fairly constant for the rest of the period covered by the baseline flight traffic model. The average annual usage from 1983 onward is about 1125 CAMAC units per year and 450 NIM units per year. It should be noted that these numbers represent the projected usage in contrast to the number of units that must be procured annually.

NIM/CAMAC EQUIPMENT PROCUREMENT REQUIREMENTS FOR A POOL APPROACH

NIM/CAMAC procurement requirements for a pool approach were determined after taking the following factors into account:

- Time span over which equipment is needed for a flight
- Use of commercial counterparts is recommended for payload development
- Replacement rate of pool equipment
- Spare units for contingencies

NIM/CAMAC EQUIPMENT PROCUREMENT REQUIREMENTS FOR A POOL APPROACH

The amount of NIM/CAMAC equipment that must be procured each year to support the projected usage with a pool approach was determined by calculating the numbers of each type of module that must be added to the pool each year to maintain an inventory that is at least equal to the number of units to be used in the year. These results were then adjusted to take several important factors into account.

The time span over which pool equipment must be committed for a given flight was analyzed and the following values were used in this task: Level IV through Level I payload integration, six months; post-flight calibration, disassembly and recertification, three months; instrument development by experimenter prior to Level IV integration, nine months.

With respect to the instrument development phase, the use of commercial modules is recommended for the following reasons: overall costs are reduced by decreasing the commitment period for flight NIM/CAMAC equipment from eighteen months to nine months; maintenance of the certified status of the flight equipment is simplified since it does not leave direct NASA control; experimenter flexibility is increased during the instrument development phase.

Analysis of the required equipment replacement rate indicated that obsolescence would be the controlling factor and would limit the effective life of the equipment to seven years. In the case of more extensively modified units, a seven-year replacement cycle was used. For the case of minimum modifications, the replacement rate was increased to a four-year cycle since failures and maintenance cycle costs are not expected to be negligible.

Finally, the approach used for spare units provided a forty percent contingency in the early years when the pool is small, and decreased the contingency to an average of fifteen percent when the pool reached maturity. This also had the desirable effect of smoothing out the procurement time profile.

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OF POOR QUALITY

NIM/CAMAC COSTS FOR POOL APPROACH

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
POOL SIZE	500	785	1200	1720	1720	1800	1800	1850	1850	1850	1850	1850
UNITS PROCURED PER YEAR												
MINIMUM MODIFIED	500	410	611	820	430	510	450	500	463	463	463	463
MAXIMUM MODIFIED	500	356	527	691	246	326	257	307	264	264	264	264
EQUIPMENT COSTS (M$)												
COST/YEAR												
MINIMUM MODIFIED	1.15	0.66	0.92	1.23	0.60	0.71	0.63	0.70	0.65	0.65	0.65	0.65
MAXIMUM MODIFIED	4.25	1.71	2.30	2.59	0.92	1.22	0.96	1.15	0.91	0.99	0.99	0.99
CUMULATIVE												
MINIMUM MODIFIED	1.15	1.81	2.73	3.96	4.56	5.27	5.90	6.60	7.25	7.90	8.55	9.20
MAXIMUM MODIFIED	4.25	5.96	8.26	10.85	11.77	12.99	13.95	15.10	16.01	17.00	17.99	18.98

NIM/CAMAC COSTS FOR A POOL APPROACH

The total number of NIM/CAMAC units needed in the equipment pool to support the projected usage is shown on the facing page along with the corresponding yearly procurement requirements calculated in accordance with the previous discussion. What have previously been referred to as "more extensive" modifications are denoted as "maximum" modifications in the tabulation for convenience.

The cost estimates developed in Task 3 were used to calculate the average NIM/CAMAC unit cost, including nonrecurring development, as a function of the number of units procured for both levels of modification. The pool equipment cost estimates on the facing page were generated using those relationships and the detailed breakdown of the yearly procurement requirements for each type of NIM and CAMAC equpment item.

Two significant points about the cost estimates should be noted. First, the pool equipment costs are relatively low, especially after initial pool buildup. Second, although the more extensively modified units are initially four to five times as expensive as the minimally modified units, the difference over the twelve-year time period is only a factor two due to the large quantity of units procured.

The cost estimates to this point only cover the flight NIM/CAMAC pool equipment. If the cost of commercial units for instrument development and the pool operational costs are added, the total cumulative pool costs for the 1980-1991 time period go to about $21 million and $31 million for the minimum and more extensive modification cases, respectively. Thus, we see that the cost differential between the two levels of modification becomes less significant when the fixed "overhead" of the equipment pool is taken into account.

RECOMMENDED NIM/CAMAC EQUIPMENT POOL MANAGEMENT

- The amount of equipment required cannot justify more than one central pool with the possible later addition of a satellite pool
- The central pool would be responsible for:
  - Procurement of flight-qualified equipment
  - Distribution of equipment to users
  - Maintenance and calibration of flight-qualified equipment
  - Provision of technical information and support to users
- The estimated operational cost of the pool rises from an initial level of \$385K/year in 1980 to \$670K/year after 1984

RECOMMENDED NIM/CAMAC EQUIPMENT POOL MANAGEMENT

Our investigation of the alternative approaches to equipment pool organization indicated that none of the factors that might offset the overall cost advantages of a centralized pool were significant enough to justify a multiple pool approach. This conclusion depended upon the concept of using commercial units for instrument development to provide the flexibility needed to respond to frequently changing requirements from widely dispersed users as well as the fact that critical requirements for rapid service from the pool would mostly arise only at the Shuttle flight centers (KSC and VAFB).

Therefore, the recommended pool concept involved a central pool control center and pool equipment disbribution centers at the Shuttle flight centers. The largest pool of equipment would logically be located at KSC with a satellite pool at VAFB coming into operation when Spacelab operations there require it.

The central control center would handle overall pool management, procurement of flight NIM/CAMAC equipment and provision of technical information and support to users. The pool equipment distribution centers would handle the distribution of equipment to users and the maintenance of flight equipment.

The level and cost of the manpower required to operate the recommended pool system was estimated and found to initially be $0.35 million per year when only the KSC pool was operating. This cost would rise as the pool size increased to a level of $0.67 million per year when the pool system reached maturity in about 1984. The costs should not be considered to be uniquely attributable to the use of a pool approach since comparable functions must be performed in any implementation.

NIM/CAMAC EQUIPMENT PROCUREMENT REQUIREMENTS FOR DEDICATED APPROACH

- Equipment was assumed to be dedicated to individual payloads
- The number of baseline model flights involving new payloads was estimated on the basis of SSPDA
- NIM/CAMAC equipment procurement requirements and costs were determined in a comparable way as for the pool approach
- The cost of comparable custom-built equipment for the same new payloads was estimated

NIM/CAMAC EQUIPMENT PROCUREMENT REQUIREMENTS FOR A DEDICATED APPROACH

Implementation approaches that assumed the NIM/CAMAC equipment used by each payload to be dedicated to that payload and not available to other users were considered to determine the cost reduction realized by using a pool approach. The dedicated equipment approach is applicable to either standard NIM/CAMAC equipment or functionally equivalent equipment custom-built in accordance with normal aerospace practices.

In order to establish the procurement requirements for a dedicated-equipment approach, it was necessary to estimate the actual number of . new paylaods in the baseline Spacelab flight traffic model as opposed to reflights of an existing payload. The information on mission frequency contained in the SSPDA documents was used to estimate the number of new paylaods in the model.

Given this information, the determination of the NIM/CAMAC equipment procurement requirements and costs were estimated in a way that was comparable to that used for the pool equipment. It was optimistically assumed that, even though the equipment would be dedicated to individual payloads, the procurement of identical units for the various payloads would be consolidated.

Finally, to assess the cost impact of standardization, the comparable cost of functionally equivalent custom-built equipment for the same new payloads was estimated. In this case, the consolidation of procurements between payloads was ruled out by definition, but it was assumed that advantage would be taken of commonality within each payload to amortize nonrecurring development costs. In addition, twenty percent spares were assumed, but no replacement was included.

NIM/CAMAC EQUIPMENT COSTS FOR DEDICATED APPROACH

YEAR	1980	1981	1982	1983	1984	1985
NEW PAYLOADS/YEAR	2	6	8	4	1½	1½
UNITS PROCURED/YEAR						
MINIMUM MODIFIED	383	656	1064	888	645	705
MAXIMUM MODIFIED	383	615	963	698	408	458
CUSTOM-BUILT	383	560	828	445	91	128
EQUIPMENT COSTS (M$)						
COST/YEAR						
MINIMUM MODIFIED	0.88	0.98	1.49	1.24	0.90	0.99
MAXIMUM MODIFIED	3.26	2.74	3.35	2.15	1.26	1.41
CUSTOM-BUILT	8.66	16.60	24.40	12.65	3.80	4.56
CUMULATIVE						
MINIMUM MODIFIED	0.88	1.86	3.35	4.59	5.49	6.48
MAXIMUM MODIFIED	3.26	6.00	9.35	11.50	12.76	14.17
CUSTOM-BUILT	8.66	25.26	49.66	62.31	66.11	70.67

NIM/CAMAC EQUIPMENT COSTS FOR DEDICATED APPROACHES

The results of the review of the SSPDA documents to determine the number of new payloads reflect the fact that there is a very large number of reflights projected. In fact, if the SSPDA data are simplistically taken at face value, essentially no new instruments or payloads are identified after 1985. Since this is undoubtedly not a realistic representation of Spacelab payload operations, we only carried out estimates to 1985.

The estimated equipment procurement requirements and costs are shown on the facing page. For the 1980-1985 time period, the total number of NIM/CAMAC units that must be procured is about thirty-three percent higher than the comparable requirement for pool equipment. The difference in cumulative costs compared with the pool approach is not as great because of the assumption of consolidated procurement. Although the frequency of reflights has probably been overestimated, these results do indicate that the cost saving to be realized with a pooled-equipment approach may not be as great as might be expected.

On the other hand, the cost of comparable custom-built equipment can be seen to be very significantly greater than any of the approaches using standard NIM/CAMAC equipment. This is primarily due to the greatly reduced amortization of nonrecurring development costs rather than the slightly higher recurring unit cost used for the custom-built equipment.

TASK 4B - IMPLEMENTATION AND IMPACT OF CAMAC SOFTWARE

Scope of Work

- Survey and summarize existing CAMAC software systems
- Survey and summarize current information on the Spacelab software system
- Investigate a system of pooled CAMAC support software
- Analyze major software requirements for two payloads

TASK 4B - IMPLEMENTATION AND IMPACT OF CAMAC SOFTWARE

Four existing CAMAC software systems were selected from the available examples. These four systems provide a reasonable sample of the range of CAMAC software system concepts used in different applications that each have at least some key requirements that will be encountered in implementing Spacelab payload software. All of the available documentation on these software systems was obtained and a summary of the relevant features of each was prepared with an emphasis on their approach to user application program implementation.

Next, the available documentation describing the Spacelab software environment for payloads was reviewed and summarized with emphasis on those features most relevant to payloads using CAMAC hardware.

The results obtained in the surveys of existing CAMAC software systems and the Spacelab software system were applied to investigate software implementation for CAMAC systems used in Spacelab. Functional criteria were identified to distinguish two general categories of CAMAC usage in Spacelab payloads and recommended approaches to handle each were formulated. The types of standard CAMAC software to be provided for users were defined and the impact of the use of CAMAC hardware on experiment software development costs was assessed.

Finally, the major software requirements were analyzed for two of the representative payloads selected and analyzed in Tasks 1 and 2. Top level software system diagrams were developed to provide specific examples of the recommended approaches to CAMAC software implementation and the standard CAMAC interface subroutines required by each payload were identified.

GENERAL SOFTWARE SYSTEM REQUIREMENTS

- Software system for experiment operation consists of the following major elements:
    - Operating system for processor
    - Input/output drivers
    - Utility library
    - Applications program
    - Software development aids
- Use of standard CAMAC hardware impacts the software system by allowing the use of standard input/output drivers for the CAMAC hardware

GENERAL SOFTWARE SYSTEM REQUIREMENTS

The following major elements are required in a software system to be used for experiment control and data acquisition:

- The operating system for the processor which handles executive services such as task scheduling, system resource allocation and system initialization and loading.
- Input/output drivers which handle data transfers to and from peripheral hardware.
- A utility library which provides commonly-used computation and analysis routines, display control routines, etc.
- The application program which defines the sequence of operations required by the experiment.
- Software development aids such as high-order language compilers, assemblers, editors and simulators.

All of these elements except the applications program, which must be developed for each specific experiment, are usually provided to the user by the host software system and certainly should be provided for Spacelab users. The magnitude of the experiment software effort depends critically on the availability and convenience of use of these software system elements. Ideally the experiment software development should only involve developing the applications program.

The use of CAMAC hardware really only directly impacts the software system by allowing the use of standard input/output drivers for the CAMAC hardware. The drivers should ideally make the details of the host software system as transparent as possible to the user.

EXISTING CAMAC SOFTWARE SYSTEMS

- Data acquisition and process control system at the Hot Fuel Examination Facility
- Basic instrument for the support of on-line needs (BISON) at the Fermi National Accelerator Laboratory
- Software system for data acquisition in nuclear physics experiments using CAMAC at Los Alamos Scientific Laboratory
- CAMAC support library for industrial systems at ALCOA

EXISTING CAMAC SOFTWARE SYSTEMS

The Data Acquisition and Process Control System at the Hot Fuel Examination Facility is primarily a dedicated system for computerized automatic control and data acquisition of fuel element examination via two CAMAC parallel highways. The software system is relatively static because of its dedicated function. The software system, operating on a Datacraft 6024/3 central processor, makes extensive use of assembly language to achieve high operating efficiency.

The BISON system at Fermilab provides high speed communications links using CAMAC equipment to interconnect two central CDC 6600's with a variety of user minicomputers (mostly DEC PDP-11's) in a multiplexed star network. The software system provides for efficient, transparent data transmissions between users and the central computers. In addition, a CAMAC software library is provided to support experiment software development in FORTRAN.

The software system for data acquisition in experiments using CAMAC at Los Alamos is designed to support high-speed data acquisition on CAMAC systems controlled by a PDP-11 via a microprogrammable branch driver. The software system provides CAMAC drivers for the PDP-11/branch driver combination, utility routines and a special task-oriented language interpreter to facilitate user application program development.

The CAMAC support library for industrial systems at ALCOA provides an extensive library of computer-independent software modules to facilitate the development of diverse portable applications programs in standard ANSI FORTRAN supplemented by standard ISA bit manipulation routines. A wide repertoire of computer/branch driver-specific CAMAC drivers are available with a standard FORTRAN call sequence. A flexible logical device table generator scheme is included to handle diverse or variable hardware configurations with minimum software impact.

SPACELAB SOFTWARE SYSTEM

- Spacelab CDMS software system will provide:
  - CDMS computer operation system
  - Input/output drivers for CDMS peripherals
  - Limited utility routines from flight application software
  - Various simulators
  - HAL/S and GOAL compilers plus assemblers and editors
- Principal user problem will be unfamiliarity with HAL/S high-order language or MITRA 125 assembly language

SPACELAB SOFTWARE SYSTEM

The Spacelab software system (as currently defined in the "Spacelab Payload Accommodations Handbook", ESA, May 1976) will in principle provide all of the software system elements required for a convenient experiment software development. These include the following:

- An operating system for the Spacelab computers (MITRA 125).
- Input/output drivers for all standard Command and Data Management System (CDMS) peripherals.
- Limited utility routines from the flight applications software package.
- CDMS and MITRA 125 simulators that execute on an IBM 370.
- HAL/S and GOAL high-order language compilers plus MITRA 125 assemblers and editors that execute on an IBM 370 or the MITRA 125.

The principal user problem that we expect to be encountered will be unfamiliarity with the HAL/S high-order language and the MITRA 125 assembly language that are the only choices available for experiment applications programs that execute on the Spacelab experiment computer.

CAMAC-SUPPORT SOFTWARE SYSTEM FOR SPACELAB

- For facility use of CAMAC, efficient assembly language software tailored to the application is justified
- For experiment use of CAMAC, a convenient user-oriented software system is required including:
  - CAMAC driver for MITRA 125
  - HAL/S callable subroutines for each type of CAMAC module in use
  - Logical device table generator to provide minimum software dependence on hardware configuration
- If the complete CDMS software system is available, the use of CAMAC hardware will reduce software costs only slightly. Cost reductions will be more significant if the host software system is limited.

CAMAC SUPPORT SOFTWARE FOR SPACELAB

The applications of CAMAC in Spacelab payloads fall into two general categories. The first of these is the use of CAMAC to implement what we have termed facility-type functions. For this case the requirements change either very little or not at all as the payload is reflown. The second category is the use of CAMAC to implement the experiment-specific functions which change as new instruments are accommodated or experiment procedures are modified.

For the facility use of CAMAC, the repeated usage and relatively static requirements justify a greater one-time effort to develop assembly language software that is tailored to the specific applications and maximizes the operating efficiency. The Hot Fuel Examination Facility software system is an example of this approach.

For experiment-specific use of CAMAC, the variability of the software requirements means that software development will be continuing process. Therefore, a convenient, user-oriented software system is preferable in spite of its reduced operating efficiency. The choice of this approach is strengthened by the expected unfamiliarity of users with the languages that will be available in the Spacelab software system. The ALCOA software system is an excellent example of an appropriate approach. The key standard CAMAC software elements of such a system include:

- A standard CAMAC input/output driver for the MITRA 125 and whatever CAMAC branch driver is adopted.
- Standard HAL/S callable subroutines for each type of CAMAC module in use.
- A flexible logical device table generator to provide minimum software dependence on the hardware configuration.

The software cost impact of the use of CAMAC will depend on the host software environment which is available. If the complete Spacelab software system is available, the addition of the standard CAMAC software will greatly simplify the user effort devoted to input/output data transfers between the Spacelab computer and his experiment hardware, but this represents only a portion of the users' application program development task. On the other hand, if the available Spacelab software support is limited or inconvenient to use, the availability of standard CAMAC software can save a considerable amount of the user effort that would be required to develop special input/output drivers specifically for his experiment.

SOFTWARE REQUIREMENTS FOR THE IR TELESCOPE PAYLOAD AND THE X-RAY/GAMMA-RAY PAYLOAD

- SIRTF provides an example of both facility-type CAMAC usage and experiment-specific CAMAC usage
  - SIRTF instrument data acquisition and control requirements are compatible with a standard CAMAC software approach
  - SIRTF fine pointing and telescope housekeeping are best implemented with dedicated software
- X-ray/gamma-ray data acquisition and control requirements can be handled in a straightforward way with a standard CAMAC software approach

SOFTWARE REQUIREMENTS FOR THE IR TELESCOPE PAYLOAD AND THE X-RAY/GAMMA-RAY PAYLOAD

The Shuttle Infrared Telescope Facility (SIRTF) is a good example of a payload that requires both facility-type CAMAC usage and experiment-specific usage. The telescope itself and its control and data acquisition systems are a permanent part of the facility that will be flown many times without modification. The complement of focal plane instruments, on the other hand, can be expected to change for each flight. A software system design was developed that integrates the recommended software implementations for each type of requirement.

Three assembly language subroutines handle the SIRTF fine pointing and telescope housekeeping requirements. The use of CAMAC hardware has essentially no impact on this portion of the software.

The focal plane instrument data acquisition and control requirements are implemented with the recommended standard software approach. Only seven standard CAMAC module subroutines plus the standard CAMAC driver are needed for the five instruments included in the representative payload..

The X-ray/gamma-ray payload data acquisition and control requirements provide an example for which the standard CAMAC software approach is very well suited. The software system design incorporates three major categories of software: standard CAMAC software modules, Spacelab-provided software, and a user-provided application program that can be written in high-order language.

Although the three instruments in this payload use over one-hundred CAMAC modules, only ten standard CAMAC module subroutines plus the standard CAMAC driver are needed to provide transparent communications between the application program and the instrument hardware.